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The Relationship Between Semantic Search and Semantic Priming

Lily Rachel Mencarini
Bard College

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by
Lily Mencarini

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Dedication

This is dedicated to all of the past Lilys, who never thought they'd make it this far.

Acknowledgements

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Abstract

Memory is an essential skill for survival but also very complicated. Semantic memory is an aspect of long-term memory that consists of words and facts about the world. This study aims to see if there is a relationship between semantic priming and semantic search. There were 57 participants with full data who took both the Remote Associates Test (RAT) and a primed lexical decision task (LDT). The RAT tests for semantic search abilities and the primed LDT tests semantic priming ability. It is hypothesized that participants who get faster reaction times (RTs) on correct trials of the RAT will have faster RTs on correct trials of the primed LDT. It is also hypothesized that there will be a correlation between number of correct trials on the RAT and number of correct trials on the RAT per participant. If these data are related, this may indicate that semantic search and semantic priming may be controlled by the same mechanism. It was found that there is a positive correlation between number of correct trial on the RAT and primed LDT. However, there was no relationship found between the RTs on correct trials of the RAT compared to RTs on correct trials of the primed LDT. This indicates that there is some support for semantic search and semantic priming sharing the same mechanism, but not strong support. Perhaps the underlying processes somewhat overlap between semantic search and semantic priming. Future research could look into this relationship more precisely, such as with brain imaging, and potentially find out the mechanism behind semantic priming and semantic search.

Semantic memory is a form of long-term memory that consists of knowledge about word meaning and concepts. For example, knowing that cats meow and dogs bark is part of semantic memory. Semantic memory is crucial for everyday life, as it allows us to know what words mean so we are able to speak and write, in addition to knowing general facts about the world. Those with semantic dementia or lesions in certain areas of the brain have diminished or no semantic memory which makes their lives very difficult. Imagine trying to go about life without knowing that a spoon is called a spoon. It would make it hard to communicate that you needed a spoon if you could not find the name for it. Everyone occasionally experiences not being able to remember the word for something, but for those with semantic memory problems, that is a constant experience. Figuring out the mechanism behind semantic memory could help with potential treatment for these people.

In order for people to access the knowledge stored in semantic memory, this can require an effortful search. If I ask you what the capital of Canada was, you would likely need to search your brain for the answer, thinking about different related concepts like major cities in Canada and capitals of other countries. If you don't know what the capital of Canada is, then that information does not exist in the network of your semantic memory and the search will be unsuccessful. Semantic search is a process that happens frequently while going about your everyday life, even if you might not notice it at first.

Another aspect of semantic memory is semantic priming. If concepts and words exist in a network in our brain, then when one node is activated (you think about apples), then related concepts and words are activated and more easily come to mind (such as bananas, oranges, and red). This is an automatic process that happens in the brain constantly. Concepts and words that are regularly associated (such as dogs and cats) have a strong connection and will therefore activate one another when you think about one. Other concepts are more weakly connected to each other, such as how when you think of colors, you probably first think of red, blue, and other colors of the rainbow as opposed to chartreuse or periwinkle. These are colors too, but because we hear the words less frequently and are therefore exposed to them less, they are not as strongly connected to the concept of color and will usually not be primed immediately.

Both semantic search and semantic priming are essential aspects in day-to-day life. Understanding semantic search and semantic priming will reveal more information about how the brain works which could help people with impaired semantic memory. It can also assist in creating more accurate neural networks on computers. I speculate that it is possible that semantic search and semantic priming both function on the same or similar mechanisms in the brain. The Spreading Activation Model (Collins & Loftus, 1975) may account for both of these processes or at least be similar to it.

My research question is: What is the relationship between semantic search and semantic priming? The Remote Associates Test (RAT) can assess semantic search ability, and a primed lexical decision task (LDT) can assess semantic priming ability. I hypothesize that participants who have faster reaction times on the RAT (remote associates test) will have faster reaction times on a primed lexical decision task (LDT) than those who are slower on the RAT. Additionally, I hypothesize that the number of correct trials on the RAT will be correlated with the number of correct trials on the primed LDT. If there is a correlation between the scores on the RAT and the primed LDT, this may indicate that both of these processes share the same or related mechanisms. This may give more insight into the structure of semantic memory.

What is Semantic Memory?

Semantic memory is a form of explicit, long-term memory. Explicit memory (semantic and episodic) differs from implicit memory (e.g. muscle memory) in that the person thinking is aware they are having thoughts about these memories. Semantic memory contains information about the world and facts. It is different from episodic memory, also known as autobiographical memory, which involves memories from events a person has experienced themselves (Tulving, 1972).

One theory of how semantic memory works suggests that it exists in a dynamic, holographic network, with words and concepts connected in an organized space (Franklin & Mewhort, 2015). A holographic network is a proposed map of semantic space where words and concepts are organized similar to light particles in a hologram (Franklin & Mewhort, 2015). It is dynamic in the sense that the network changes - some connections strengthen while others weaken - with incoming information (Davelaar, 2015).

The neuroanatomy of semantic memory has been widely debated, and an overarching theory has recently been formulated. The 'hub-and-spoke' theory describes an organization that involves a widespread network of information around its modality specific hub (Patterson & Lambon Ralph, 2016). For example, concepts surrounding what color objects are is found near the areas of the brain that process vision. The knowledge that an apple is red is stored in the visual cortex. The knowledge that a duck makes a quack sound is stored in the auditory cortex. Both verbal and non-verbal concepts are stored in their respective cortices, with areas for vision, speech, function (such as how to use an object), sound, valence (how positive or negative something is), and praxis (learned movement). These make up the 'spokes' in this theory. The 'hub' is identified as the anterior temporal lobes (ATLs), a centralized location where all of the different modality specific information converges and is processed, at least in part (Ralph et al., 2016).

While the ATLs are important for converging conceptual information, and modality specific cortices are important for holding information, this information still needs to be retrieved and applied. There are separate systems for semantic representation (explained above) and semantic control (such as retrieval). This seemingly is done in parts of the prefrontal cortex, in addition to a few other areas of the temporal parietal cortex (Ralph et al., 2016).

Semantic Search

In order to recall words and semantic concepts, there needs to be a search of the semantic network. There are different types of search that can take place. Global search involves looking at the entire semantic network (Hills et al., 2012). Local search involves only looking at a small area that connects to one specific word/concept (Hills et al., 2012). Latent search is when one is given a global term (e.g. plants) and then narrows that down to a smaller subcategory (e.g. vegetables) which is then searched (Davelaar, 2015). Some items are still in the semantic set but more weakly connected (e.g. okra for cue word vegetable). It is likely local or latent search will be needed to recall these items as a global, less specific search may overlook them.

Supposedly, when a cue is given, the memory space is divided up to only include the activated items, which is called the memory search set. Similarly, according to the patch model, the items first retrieved when given a cue are called a patch. These sets/patches are more divided off when given additional cues, shrinking the area that needs to be searched. For example, when given the cue ‘animals’ and asked to come up with as many items in that category as possible, a specific patch/memory search set will be formed. If the animals also have to be red, this decreases the number of items that fit in the patch, making it easier to search for a specific item.

If the target word is ‘lobster’, adding the red cue will make it faster to search for the target, as the patch is smaller. These converging inputs of cues are thought to combine in a multiplicative way (Davelaar, 2015).

With a verbal fluency test such as free association, many targets are available from one cue word. The cue word for example could be ‘plant’ so the participant is asked to name as many plants as possible. People tend to report items in categories, such as first starting with types of flowers until they run out of items, then moving to vegetables, then to fruit. This is modeled by optimal foraging theory, which is a model based on how animals forage for food. They move to a patch, deplete all of the resources from that patch, and move to another one. It is proposed to work the same way for semantic memory, where participants move to a patch until they deplete all of the items in it and then move to the next.

Memory search is theorized to consist of an automatic portion and a controlled process. For the automatic part, being presented with a cue word leads to the automatic spreading of activation among related concepts. When given the word apple, the brain will automatically activate associated topics such as banana, red, fruit, etc. that are closely related and then these terms will then activate their closely related concepts and so on. This forms a network of activated words/concepts from just one cue. The controlled process requires purposeful and effortful search and is used when the target word(s) are more distantly related or when there is a large pool of possible solutions (Becker et al., 2022).

Only a few studies have been conducted looking at which areas of the brain might be responsible for the controlled aspect of semantic search. The left inferior frontal gyrus (IFG) and the left middle temporal gyrus (MTG) have both been identified as having a role in the search process. The IFG has been theorized to guide controlled retrieval and it is also activated in lexical decision tasks. The left MTG is traditionally considered to be a storage area for conceptual representations, but may also play a role in semantic control alongside the IFG. It is likely that either the IFG controls potential solution retrieval that is stored in the MTG or they both work together to control solution retrieval, pulling potential solutions from other areas of the brain (Becker et al., 2022).

The Remote Associates Test (RAT)

Verbal fluency tests like free recall aren't the only way to test semantic search and recall. For example, the Remote Associates Test (RAT) takes a different approach with multiple cue words and only one target word, as opposed to one cue word and multiple targets (Mednick, 1962). Participants are given three cue words (e.g., whale, cheese, berry) and they have to come up with a word that relates to all three (in this case, the target word would be blue). Semantic search in the RAT happens in three patches that are competing with each other, as opposed to the verbal fluency test where one patch is searched at a time until depleted. Davelaar (2015) suggests that these patches combine in a superadditive way, making the items available to search greater than if each patch was added up separately. Likely, the area immediately around a cue word, and the overlapping areas of the different patches, are the areas searched.

The RAT is commonly used to study creativity (Wu, et al., 2020) as it is considered a test of convergent thinking, as opposed to most creativity tests that involve divergent thinking (Guilford, 1968). Convergent thinking is when a problem's solution can be figured out by applying logic and rules, bringing together separate pieces of information to find a solution (Caughron et. al, 2011). Divergent thinking is when multiple, often novel or unconventional solutions are found for a problem. The RAT is also used to study insight problem solving (Danek et al., 2020), whether creativity or intelligence is used on the RAT(Lee et al., 2014; Martindale, 1972), and in relation to mental illness (E.M Fodor, 1999; Martindale, 1972).

Presentation of the cue words in the RAT potentially leads to the spreading activation of semantic nodes. The nodes are groups of cells in the semantic network that correspond to the cue words and are activated from seeing them. For example, with the cue words duck, fold, and dollar, each corresponding concept/node is activated. These activated nodes then spread to related concepts. In this example, some of the possible related concepts could be geese (cue word duck), origami (cue word fold), and coins (cue word dollar), among many others. These concepts then activate concepts they are related to and an entire network of activated semantic nodes is formed. Associations between concepts (physical pathway between neurons) that are made less frequently are not activated as strongly as concepts that are closely related and activated more frequently. This process of the activation of single cues spreading to related concepts and so forth is called the Spreading Activation Model (Becker et al., 2022).

With the RAT, the difficulty comes from the fact that the target word is typically not closely related to each of the cues. When solving a RAT problem, only the most strongly activated concepts make up the problem space. The answer to a RAT problem is often not in this network as it is only remotely related to each cue word. That means that the answer doesn't frequently come to mind quickly as it is not automatically activated because the problem space is not large enough (Becker et al., 2022).

Participants often solve RAT problems by focusing on generating possible answers from one cue word at a time, occasionally switching to another (Smith et al., 2013) . Davelaar (2015) also identifies the fact that potential answers are sometimes generated by considering all three cues simultaneously. The part of the semantic network where these words overlap is therefore searched for potential solutions. In addition, participants sometimes do a local search where incorrect solutions are used to come up with new solutions (Smith et al., 2013).

According to Becker et al. (2022), areas of the brain that are involved in solving a RAT question include the IFG and anterior cingulate cortex (ACC). The IFG was found to activate during the solution phase of the RAT and other insight problems. In addition to its recognized role of retrieving semantic information, the left IFG also may be responsible for selecting competing semantic information from working memory. In order to solve a RAT problem, the brain must focus only on the relevant answer among many incorrect potential solutions that may arise first. The right temporal gyrus also seems to play a role in inhibiting incorrect solutions that are closely related to the cue word. The ACC has also been implicated in switching attentional focus from more obvious associations to more weakly related potential answers (Becker et al., 2022).

Semantic Priming

The semantic priming effect is when a target word is first primed by a semantically related word (e.g. target word is ‘apple’ and the prime is ‘banana’), the participant is able to more quickly make judgements on the target word than if the prime was not semantically related (eg target word ‘apple’ and prime word ‘dog’).

One distinction that has to be made is the difference between semantic priming and association. Semantically related words are part of the same category or may be synonyms (duck, goose) while associated words are words that frequently appear in the same sentence (platform, boot). Words can be both associated and semantically related (duck, pond) or be unrelated and unassociated (duck, apple). According to a meta-analytic review, priming with purely semantically related words is possible (Lucas, 2000). In addition, word pairs that are both semantically related and associated show a larger priming effect (faster reaction times on LDT).

The original model for semantic priming was the Spreading Activation Model, which is considered part of semantic search. There have been several more models proposed since then, with distributed network models and multistage activation models seeming promising as they are able to explain more complex aspects of semantic priming (McNamara & Holbrook, 2003). That being said, the Spreading Activation Model may be a good jumping off point for understanding semantic priming.

Semantic priming is also studied in relation to schizophrenia. People with schizophrenia may have disorganized speech and lose associations. This seems to come from a disinhibition of spreading activation and disorganization of semantic storage, among other sources (Almeida & Radanovic, 2021).

Primed Lexical Decision Test (LDT)

In a primed lexical decision task (LDT), a word is first given as a prime, then the lexical decision is presented. For the primed LDT (Meyer & Ellis, 1970), participants are presented with a string of letters and asked whether the string is a word or not a word. It may be a congruent trial (prime is semantically related to target word), an incongruent trial (prime is not semantically related to target word), or be a nonword trial (target is not a word e.g. twume). It has been found that participants are able to make a lexical decision more quickly when the word is primed by a semantically related word rather than an unrelated word or nonword because of the semantic priming effect (Meyer & Schvaneveldt, 1971).

The RAT and Semantic Priming

A few studies have been conducted involving both the RAT and semantic priming. Smith et al. (2012) found that when participants were shown the solution word to a RAT problem prior to solving it, not knowing it was the solution, they were more likely to get the answer and do so faster. On the other hand, when they were primed with a word strongly semantically related to a RAT solution prior to solving it, this actually impeded the solution process. This was the case when the participant was unaware that they were being primed. When participants were informed that sometimes the word preceding a RAT problem would be a clue to the RAT solution, they answered faster.

Lezama et al. performed a study using both the RAT and a primed lexical decision task (2023). They found that larger semantic priming effects with strongly related prime-target pairs were associated with better performance on the RAT. Because the RAT is often used as a test of creativity, the researchers concluded that semantic memory is activated during creative processes. Lezama et al. is similar in design to the present study. It looks at the association between the RAT and a primed LDT (with some additional tasks) through the lens of creativity. The current study's purpose is to similarly look at this association, but through the lens of semantic search from the RAT.

This Study

The current study aims to look at the RAT (semantic search) and a primed lexical decision task together, seeing if there is any relation between the two. If there is a relationship between these two tests, it could indicate that the underlying mechanisms of semantic search and semantic priming may be the same. Semantic search is believed to work on the Spreading Activation Model. There are several theories surrounding the process of semantic priming, one of which being the Spreading Activation Model. Finding a relationship between the two tasks may suggest that some part of these systems is shared. Semantic search and semantic priming are somewhat different processes - search requires effortful thinking while priming is more automatic and may be done unconsciously to the participant. Because of this, there may be some differences in process but also potential for overlap. The hypotheses of this study are that participants who have faster reaction times (RTs) on correct trials of the Remote Associates Test (RAT) will have faster RTs on correct trials of a primed lexical decision task (LDT) and that the number of correct trials for the RAT will be correlated with the number of correct trials on the primed LDT.

Methods

Participants

Participants were recruited through Prolific for this study between November 1st and November 2nd, 2023. Participants first read a consent form and indicated that they wanted to participant. Based on screening criteria of being a monolingual English speaker, 58 participants were approved, 2 timed out, and 195 people returned the study for an unknown reason. In the analysis, one participant was removed from the analysis for incomplete data resulting in an analytic sample of 57. All participants were 18 years or older and were monolingual English speakers (only fluent in English). The majority of participants identified as female, followed by male and non-binary (See Table 1). The average for the age of participants was 42. The majority of the participants identified as White, followed by Black or African American. Three participants selected Prefer not to answer and one participant identified as Hispanic, Latinx, or Spanish Origin. One participant selected “Other”, and wrote in “multi” for race. Participants were paid $1.67 for their completion of the study.

Materials

Participants completed the Remote Associates Test (RAT) and a primed lexical decision task (LDT). It was randomized which task the participant received first. A brief demographics survey was used to collect data on the participant's age, race, and gender.

Remote Associates Test (RAT)

For the RAT, participants were given three cue words (e.g., whale, cheese, berry) and they had to come up with a word that relates to all three (in this case, the target word would be blue; Mednick, 1962). Questions to ask participants were selected from Normative Data for 144 Compound Remote Associate Problems (Bowden & Beeman, 2003). The first 18 questions from the Bowden and Jung-Beeman data set were picked to be used in this study, with the first three being practice problems and the remaining 15 making up the bulk of the task.

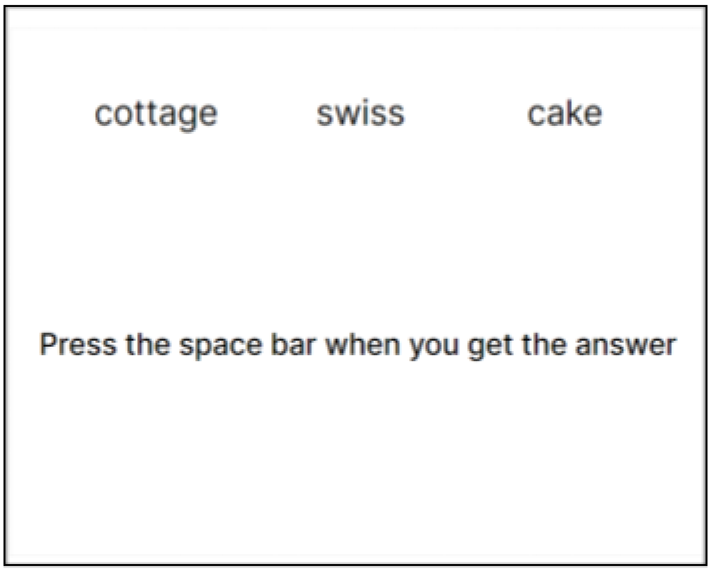
When this task started, participants were met with a set of instructions. The top of the screen said "Task Instructions" in bold and below read as follows: "You will be given 3 words and need to find the word that relates to all of them. Press SPACEBAR when you know the answer and then type it in (in lowercase). Answer as fast as you can. You have maximum 20 seconds per question." There was a Next button at the bottom of the screen that participants could click when they were ready to move on from the first set of instructions.

Once they clicked the Next button, participants were shown a blank screen for 500 ms and then given another set of instructions. The top of the screen said "Task Instructions" in bold and below read as follows: "Next will be 3 practice trials. The solution will be given after you complete a problem." There was a Next button at the bottom of the screen that participants could click when they were ready to move on to the practice section.

In the practice section, participants were first presented with a blank screen for 500 ms, then a fixation cross for 1000 ms, then a blank screen again for 500 ms. Then they saw a screen with three words at the top and instructions at the bottom, as shown in Figure 1.

Figure 1

RAT Question Screen Image



Note. This is the screen participants get after the fixation cross on the RAT.

When the participant pressed the space bar, they were given a box to type in with the instructions "Type in all lowercase" below the box. There was a "Next" button at the bottom of the screen which displayed a green check or red X depending on whether the participant was correct in their answer. Then the screen automatically advanced to a slide with the answer in blue centered on the screen. They then are advanced automatically to the next question. For the practice section, there were three trials total.

Participants then got a second set of instructions. The top of the screen said "Task Instructions" in bold and below read as follows: "You have completed the practice trials! When you click next, there will be 15 real trials for you to complete. Please try your best and go as fast as possible." There was a "Next" button at the bottom of the screen that participants could click when they were ready to move on to the real trials.

The real trials were very similar to the practice trials, except there was no feedback given. There were 15 trials total. The reaction time of pressing the space bar, and the accuracy of responses made up the main data collected. At the end of the 15 trials, a screen that said "End of Task" was presented with a "Next" button.

Primed Lexical Decision Task (LDT)

The primed lexical decision task showed participants one word briefly (prime), and then another string of letters after (target). Participants had to then press buttons to indicate whether the string of letters in front of them made up a word or not. In some trials, the prime word was related to the target word, such as "mouse" and "cheese". In other trials, the words were unrelated such as "mouse" and "blue" while other trials featured a nonword as the target such as "mouse" and "nompy". Words for this task came from the Semantic Priming Project (Hutchison, Balota, Neely, et al., 2013).

Participants were first presented with a set of instructions. The top of the screen said "Task Instructions" in bold and below reads as follows: "Press W if the letters in BLUE make a word (think of W for word) and press N if the letters in BLUE do not make a word (think N for nonword). Put your left pointer finger on the W key and your right pointer finger on the N key." There was a Next button at the bottom of the screen that participants could click when they were ready to move on from the first set of instructions.

The next screen was a second set of instructions: “Next are 3 practice trials with feedback for you to get the hang of the task.” There was a Next button at the bottom of the screen that participants could click when they were ready to move on from the second set of instructions.

This started the three practice trials. Participants were first presented with a blank screen for 500 ms, then a fixation cross for 1000 ms, then a blank screen again for 500 ms. The next screen showed a word, all uppercase and in the center of the screen for 500 ms. The following screen showed a string of letters, all lowercase and blue, in the center of the screen. This was where the participant pressed W if they saw a word and N if they saw a nonword. A red X or green check appeared under the word if they answered the task correctly. This screen was presented for 4000ms, and moved on to the next trial once that time had elapsed.

After these practice trials, the participants were presented with another set of instructions with “Task Instructions” in bold at the top of the screen and below read as follows: “You have completed the practice trials! When you click next, there will be real trials for you to complete. This should take around 5 minutes. There will be 2 breaks in the middle if you choose to use them. Please try your best and go as fast as possible.” There was a Next button at the bottom of the screen that participants could click when they were ready to start the actual trials.

There was a break after 38 trials and then after 68 trials had elapsed. The break screen read as follows “If you would like, you can take a break for up to 1 minute. When you're ready click the Next button or wait for the time to run out.” There was a Next button at the bottom of the screen that participants could click when they were ready to move on to the rest of the trials, or the screen automatically advanced after 60,000ms (1 minute).

There were 32 trials where the words are related, 32 where they were unrelated, and 32 where there was a nonword. The presentation of these trials was randomized, with a total of 96 trials. The reaction time of pressing the W or N in addition to accuracy of response was noted. At the end of the trials, a screen that said “End of Task” was presented with a “Next” button.

Procedure

This study was approved by the IRB at Bard College on October 30th, 2023. Participants with a Prolific (www.prolific.com) account were showed this study with a brief description including the amount of compensation ($1.67).

Via Gorilla (www.gorilla.sc), participants read the informed consent form at the beginning of the survey. They selected Agree in order to participate in the study after reading about the study and potential risks/benefits. If they selected Disagree to the informed consent, they were rejected from the experiment and redirected to Prolific. If they selected agree, participants were asked if they are fluent in a language other than English. If they answered Yes, they were rejected from the experiment and redirected to Prolific. If the participant answered No, they moved on to the rest of the experiment.

Participants filled out a demographics questionnaire where they were asked to input their age, gender, and race. Participants then completed either the RAT task or the primed lexical decision task. These are explained above. This was randomized. Once they finished the first task, they completed the remaining task.Participants were asked if they experienced any issues with the program during the experiment and to explain if so. This question was optional and there was a comment box for them to type in if they chose to.Participants were given a debriefing statement included in the Appendix. Participants were redirected to Prolific where they were compensated for their time.

Data Analytic Plan and Preprocessing

The hypotheses are that the average RTs on the RAT will be correlated with the average RTs on the primed LDT. The average number of correct trials on the RAT will be correlated to number of correct trials on the primed LDT. Participant data were excluded if there was no variance in responses on the primed LDT (e.g., all W or all N), more than 70% of responses are blank on primed LDT or more than 50% of responses on the RAT are blank. No participants met this exclusion criteria. One participant was dropped for incomplete data

Trials were planned to be excluded on both the RAT and primed LDT if reaction times were 3 SD away from the mean. This did not occur in the actual data analysis process despite being in the preregistration.

Ten participants had outlying average values for the RAT RTs, number of correct RAT trials, LDT RTs, and number of correct LDT trials. Two participants had outlying values on two of these measures. To address the outliers, the data were winsorized (Ruppert, 2014) in accordance with Lezama et al. (2023). This involved recoding outliers below the 5th percentile to the value of the 5th percentile for the sample, and outliers above the 95th percentile to the 95th percentile value. For the number of correct trials on the RAT, two participants had under the 5th percentile of average correct trials, and their scores were recoded to the 5th percentile (4.9 trials). For RT on the RAT, two values were under the 5th percentile and were recoded to the 5th percentile (2858.17 ms) and two values were over the 95th percentile and were recoded to the 95th percentile (10185.42 ms). The LDT data were recoded in the same way, where the 5th percentile for number of correct trials was 74.5 and two participants were recoded to that value, the 5th percentile for the RT was 450.31 ms and two participants were recoded, and the 95th percentile was 1006.10 ms with two participants recoded.12 values were changed via winsorizing.

Results

The number of correct trials per participant on the RAT ranged from 5 to 15 (M = 10.56, SD = 2.66) and RTs ranged from 2858.17 to 10185.42 milliseconds (M = 5808.08 , SD = 2178.86 milliseconds). The number of correct trials on the LDT ranged from 75 to 96 (M = 91.16, SD = 5.28) and RTs ranged from 450.31 to 1006.10 milliseconds (M = 680.778, SD = 127.04 milliseconds).

One of the primary hypotheses was that the number of correct trials per participant on the RAT would be correlated with the number of correct trials per participant on the primed LDT. In fact, the number of correct trials on the RAT were positively significantly correlated with the number of correct trials on the primed LDT $r(55) = .428$, $p < .001$. (See Figure 2). This means that participants who got more questions right on the RAT also got more questions right on the primed LDT.

The other hypothesis was that participant RT on the RAT would be correlated to the participant RT on the primed LDT. I did not find evidence for this hypothesis, RTs on the RAT were not correlated with RTs on the primed LDT $r(55) = .157$, $p = .225$. (See Figure 3). This means that participants who had faster RTs on the RAT did not have faster or slower RTs on the primed LDT. There was no relationship found between the RTs per participant of the RAT and their RTs on the primed LDT.

Table 1: Sample Characteristics (n=57)

	Mean or Percentage	N
Age, mean (standard deviation)	41.6 (13.7)	57

Range: 19-76 years		
Gender		
Male	31.6%	18
Female	64.9%	37
Non-Binary/Other	5.3%	2
Race*		
White	87.7%	50
American Indian or Alaskan Native	0	0
Asian	0	0
Hispanic, Latinx, or Spanish Origin	1.8%	1
Black or African American	12.8%	7
Native Hawaiian or Other Pacific Islander	0	0
Middle Eastern or North African	0	0
Prefer not to answer	3.5%	2
Other**	1.8%	1
RAT response time (standard deviation)	5808.08(2178.86)	57
Range 450.31 - 1006.10 milliseconds		
RAT # of correct trials, mean (standard deviation)	10.56(2.66)	57
Range: 5 - 15 correct trials		
LDT response time (standard deviation)	680.778(127.04)	57
Range: 2858.17 - 10185.42 milliseconds		

LDT # of correct trials, mean (standard deviation) Range: 75 - 96 correct trials	91.16(5.28)	57

Note. The table describes the demographic characteristics of the 57 participants with complete data.

*Multiple responses permitted

**One participant selected Other and wrote in “multi”

Figure 2

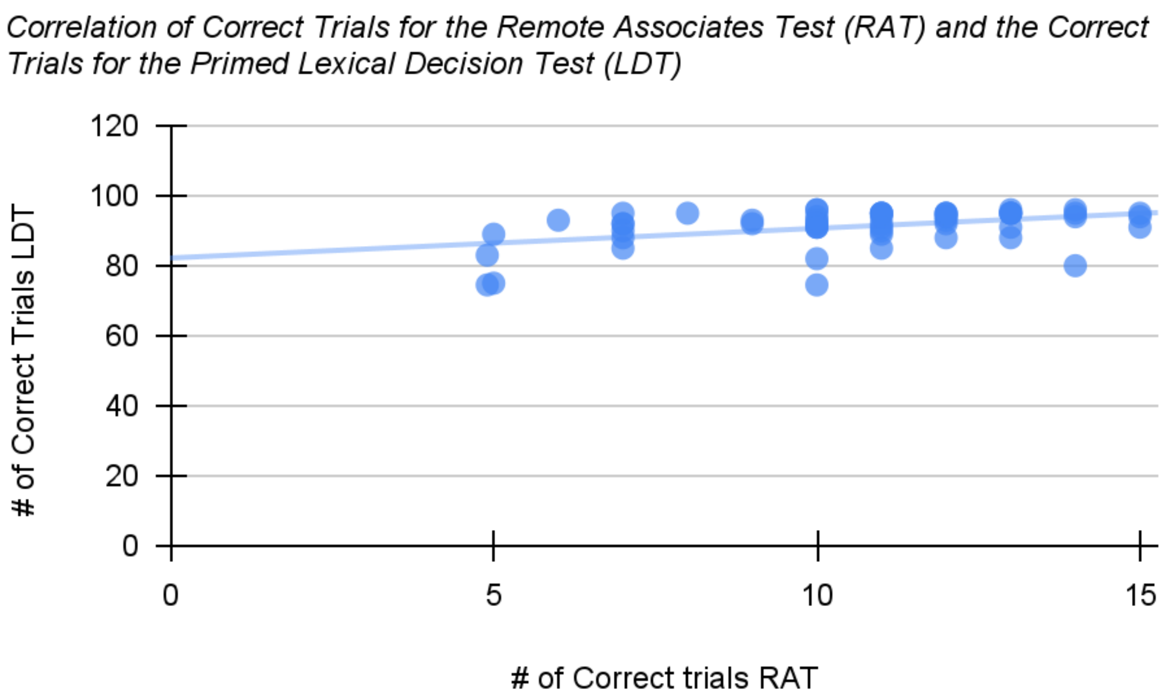
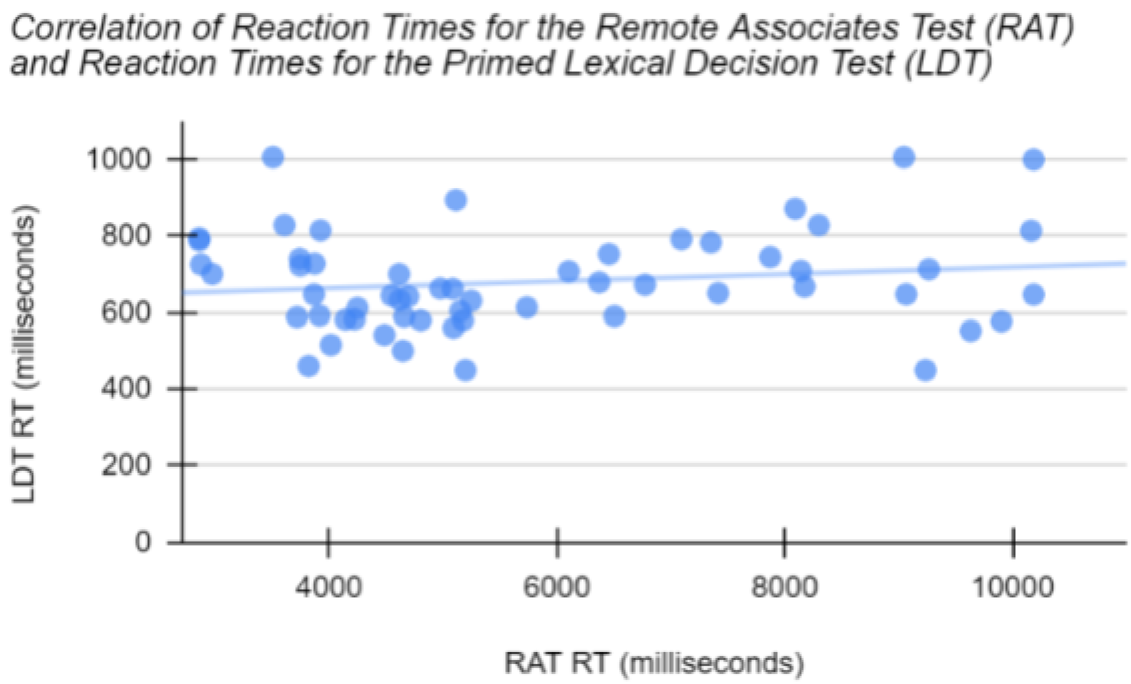


Figure 3



Discussion

It was hypothesized that reaction times on the RAT would be associated with the reaction times on the primed LDT. Additionally, it was hypothesized that the number of correct trials on the RAT would be associated with the number of correct trials on the primed LDT. There was no significant relationship found for reaction times on the RAT compared to the primed LDT; however there was a significant positive relationship between the number of correct trials on the RAT and the number of correct trials on the primed LDT. Therefore, this study lends partial support to the idea that there is a shared pathway for semantic priming and semantic search.

People use semantic search to complete the RAT (Davelaar, 2015), while they use semantic priming to complete the primed LDT. Semantic search is believed to occur with the Spreading Activation Model. There are many theories surrounding how semantic priming works in the brain. These include the Distributed Network Model (McClelland, & Rumelhart, 2020)., Compound-Cue Model (Ratcliff & McKoon, 1988; Dosher & Rosedale, 1989), Interactive-Activation Model (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982), and the Spreading Activation Model. Both the RAT and the primed LDT require the brain to think through concepts and words. Semantic priming is an automatic process while semantic search is purposeful. Despite these differences, these processes may still be related or share an underlying mechanism. If these two processes are correlated, then it might suggest that they share the same underlying process or mechanism. If it is truly the case that accuracy on these tasks is correlated while RT is not, this would mean that perhaps semantic search and semantic priming are a little bit similar in how they work but not completely.

This study found that one aspect of the tests (number of correct trials) were correlated, but not the reaction times. This suggests that it is possible these two processes share part of the same mechanism or are somewhat related. Further research should be conducted that more closely looks at semantic search and semantic priming such as with brain imaging. In addition, the RAT might not be the most sensitive way to measure semantic search, as it is typically used to measure creativity, so other tests could possibly be such as a categorization (Lorch, 1982) or naming task (Lorch, 1982). A replication of this study with a larger sample size would also allow the correlations to be more accurate, as opposed to this study with 57 participants. Future research can also be conducted regarding intelligence (Lee Bae et al., 2014), attention (Maxfield, 1997), or Alzheimer's disease (Ober & Shenaut, 1995) in relation to both semantic search and semantic priming.

Some limitations of this study, besides the sample size, include that the sample is not necessarily representative of the population. The majority of participants were female and White, which does not reflect the demographics of the United States or globally. Additionally, the RAT that was conducted in this study used only 15 problems, and the difficulty of the problems was not assessed. It is possible that these 15 problems are not representative of the difficulty of the RAT as a whole. Marko et al. (2019) discusses how cue-solution remoteness contributes majorly to participant's ability to solve RAT problems.

Data collection was done online, which poses both limitations and strengths. It is difficult to follow up with participants if there is missing data (Cantrell & Lupinacci, 2007). Only people who have access to the internet and a Prolific account were able to complete this study, which leaves many people out. On the other hand, online data collection allowed for a larger sample size for this study in addition to faster collection of data. Running experiments that collect data in person often take much longer, and it can be harder to get people to come into the lab, especially in a small environment like Bard College. People from a wider area of the country were able to participate in this study, as opposed to just local participants, in addition to having a variety of ages. If data collection was done in person, the majority of the participants would be college students aged 18 to 22, while online data collection allowed for a wider population.

This study is the first study to compare the RAT to a primed LDT in the context of semantic search and semantic priming. Lezama et al. (2023) had participants take both the RAT and a primed LDT, but this was to find out about semantic memory, attentional focus, and inhibitory control in relation to creative thinking. Looking at semantic priming and semantic search together creates the opportunity to potentially discover a larger mechanism of semantic memory. The limitations and design of this study do not allow for this to be discovered, but continued research comparing both semantic search and semantic memory could lead to such a finding.

Semantic search and semantic priming are both processes that occur frequently in our everyday life, even if we may not notice them. Without them it would be really difficult to communicate with others and the world would be much more confusing. Names of objects will be hard to recall and remembering related concepts would be slower. Overall, doing more research about semantic search and semantic priming elucidates more about the brain, the thing that controls our every action and thought.

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Appendix

Consent

Title: The Relationship Between Semantic Search and Semantic Priming

Researcher(s): Lily Mencarini

Adviser: Justin Dainer-Best, Ph.D.,
Assistant Professor of Psychology

Background: I am a senior at Bard College completing my senior project. I am looking to see if there's a relationship between the way people search their brain for words and how the brain automatically thinks about one word when thinking about another related word.

Risk and Benefits: There are no major risks to this study. There are no direct benefits to participating in this study. If at any point you feel discomfort during the study, please feel free to exit the experiment. This experiment will take about 10 minutes with optional breaks.

Compensation: Those who complete the study will receive $1.67 through Prolific.

Confidentiality: This study will ask you to provide your age, gender, and race. This data may be shared with other researchers, but no personally-identifying information will ever be accessible to others.

Further concerns: If you have any questions or concerns, you may contact Dr. Justin Dainer-Best at jdainerbest@bard.edu. If you have any questions about your rights as a participant, you can contact the chair of Bard Institutional Review Board (IRB) at irb@bard.edu.

Participant Agreement: I consent to participate in this study and acknowledge that I am 18 years of age or older.

- ☐ Agree
- ☐ Disagree

If the participant selects Disagree, they will be rejected from the experiment and they will not move on to the next question.

Language Question: Are you fluent in a language other than English?

- ☐ Yes
- ☐ No

If the participant selects Yes, they will be rejected from the experiment and they will not move on to the next question.

Demographics Questions

- How old are you?
    - Open Response (Number Only):
- With which gender do you best identify with?
    - Female
    - Male
    - Nonbinary/other
    - Prefer not to answer
- Which category/categories best describe you? Select all that apply.
    - American Indian or Alaskan Native
    - Asian
    - Black or African American
    - Hispanic, Latinx, or Spanish Origin
    - Middle Eastern or North African
    - Native Hawaiian or Other Pacific Islander
    - White
    - Wish not to disclose
    - Other (please specify):

Debriefing Section

Did anything seemingly go wrong during the experiment? Explain below if so.

(Open response)

Debrief Statement

Thank you for participating in my study! The purpose of this study is to look at how words are connected and searched for in our mental web of vocabulary. You completed 2 tasks, the Remote Associates Test (RAT) and a semantic priming task. I am looking to compare the results of these tasks and see if there's a relationship between them. My hypothesis is that those who score high on one test will also score high on the other. Thank you again!

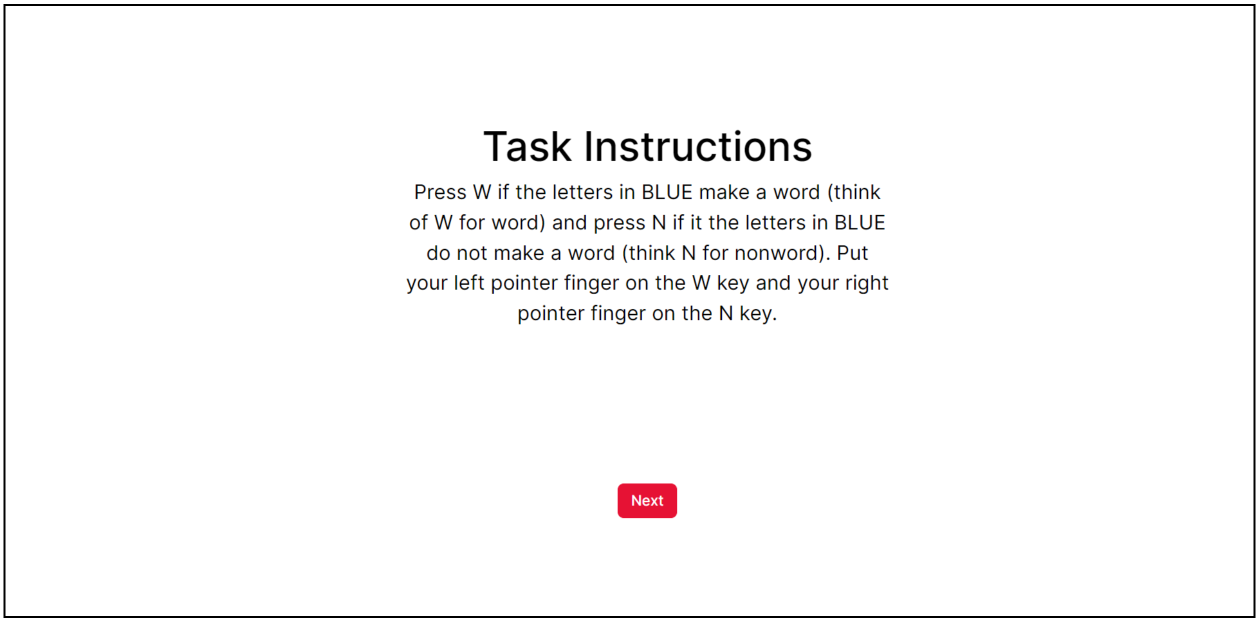
a. If you have any questions about this study, you can email lm8967@bard.edu
b. If you have any questions about your rights as a participant, you can contact the chair of Bard's Institutional Review Board (IRB) at irb@bard.edu.

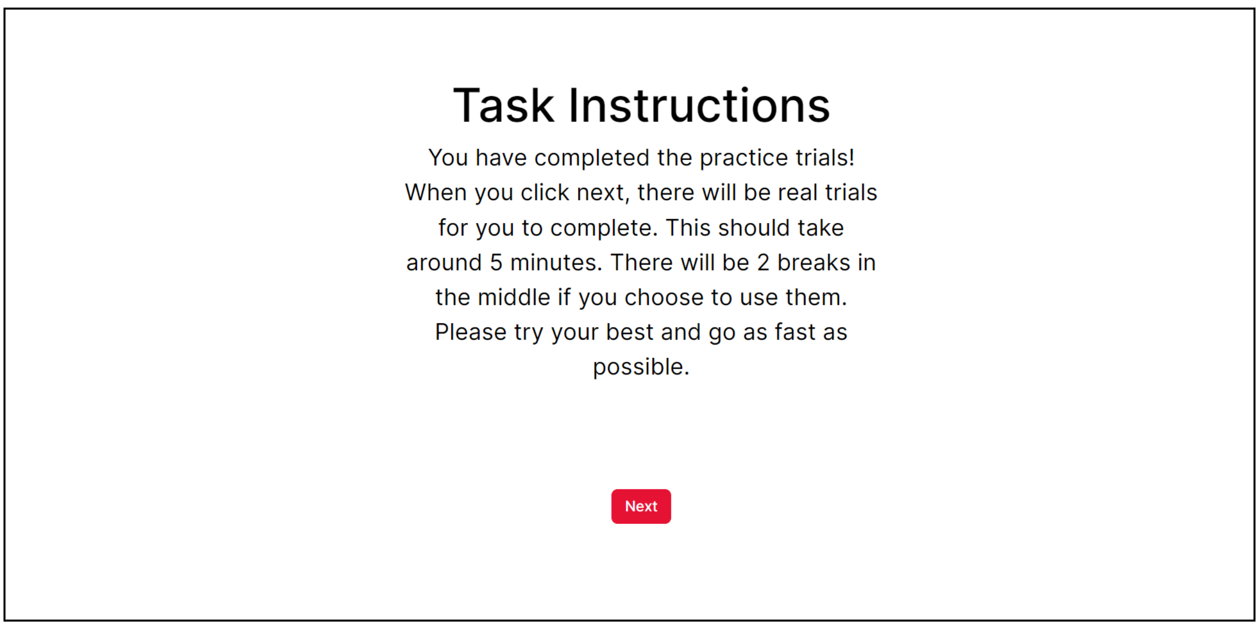
Recruitment Materials

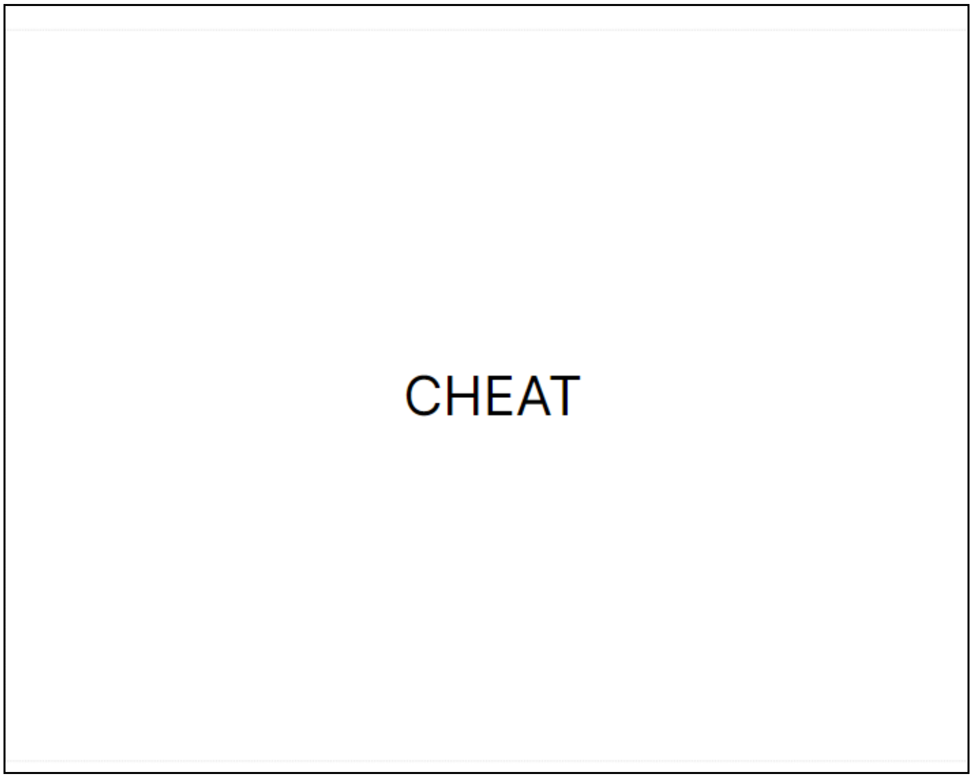
This study is interested in how words are connected and selected in our brains. You should complete this task on a computer (not a phone or tablet). You will be asked to answer two questions, complete demographic questions, and complete two tasks in your browser which do not involve any downloads. The approximate time to complete the study is about 10 minutes and you will receive a payment of $1.76.

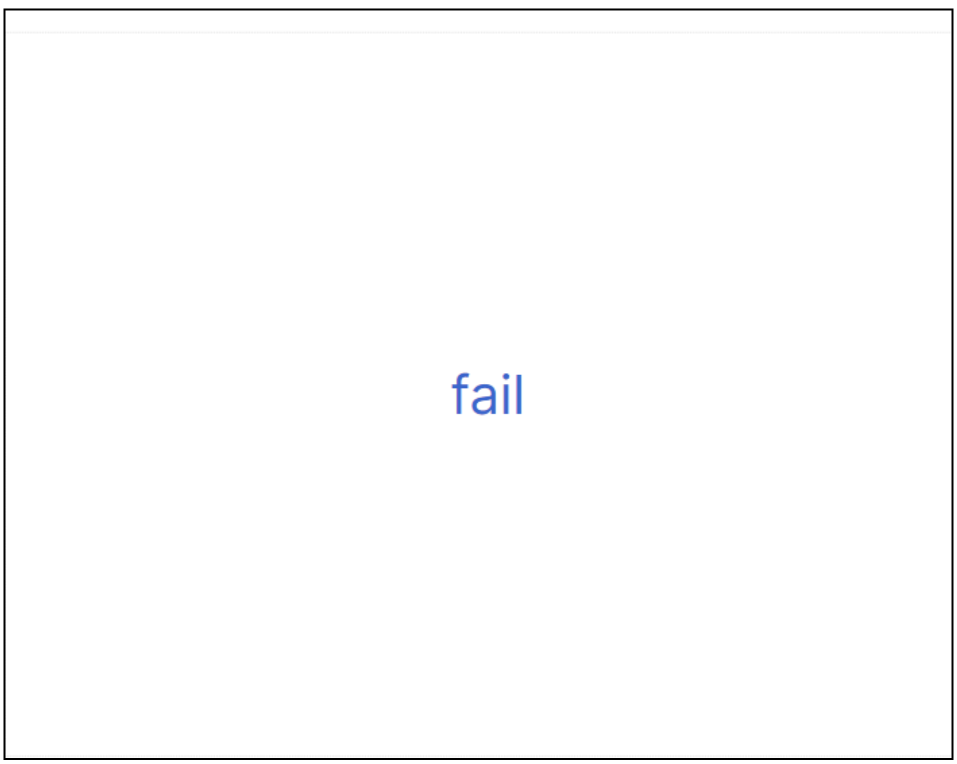
Screenshots of Tasks

Primed LDT Images

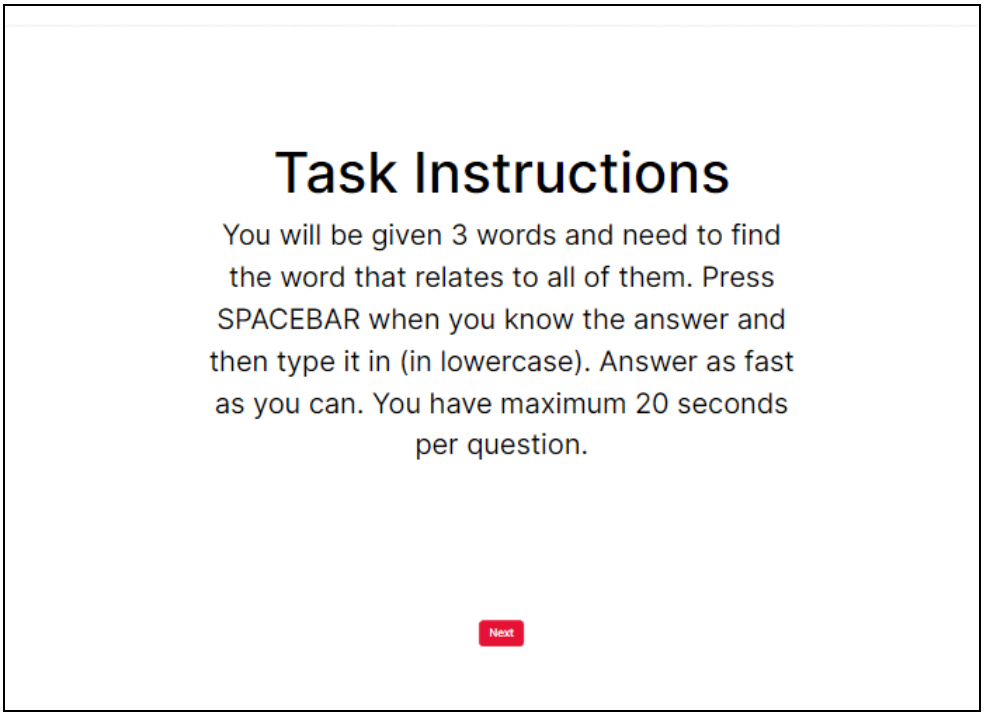


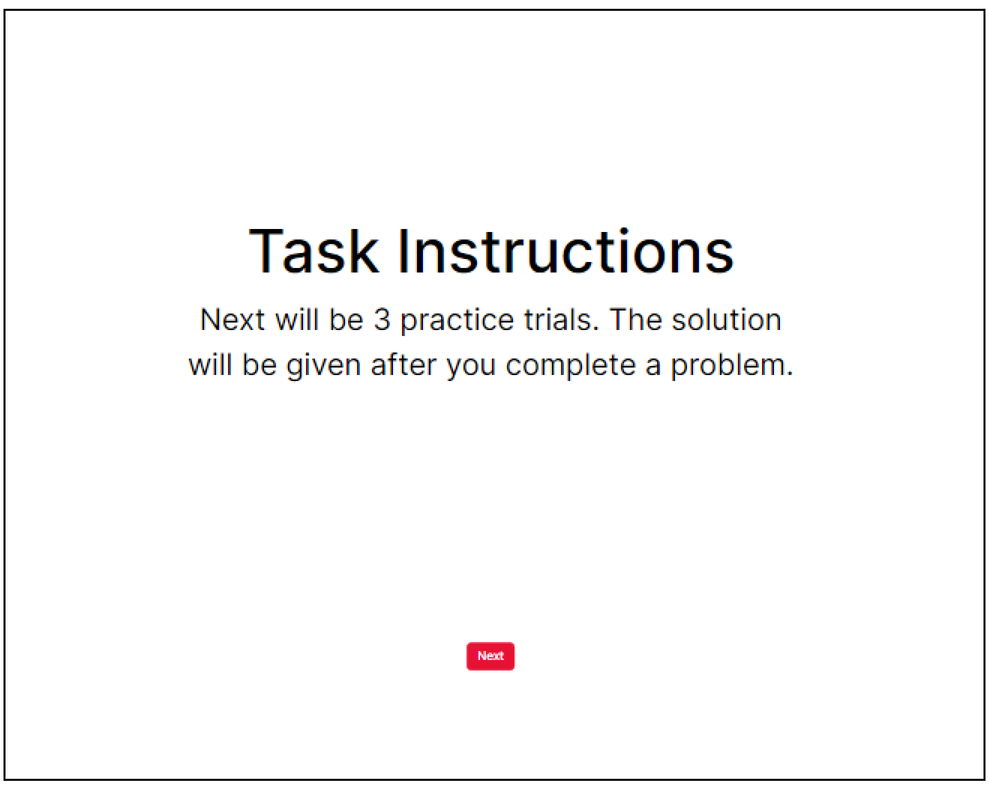


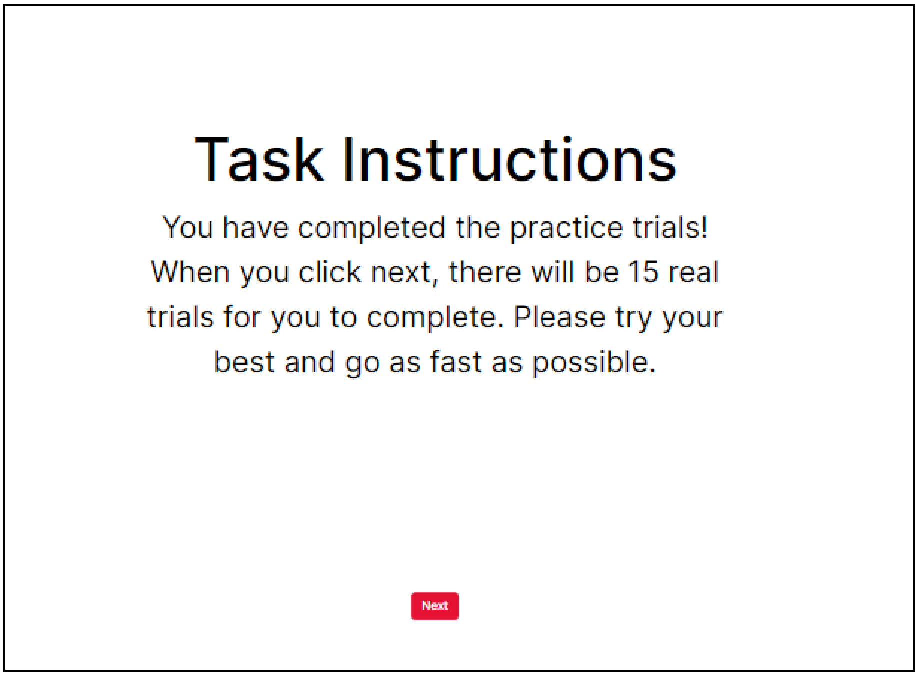


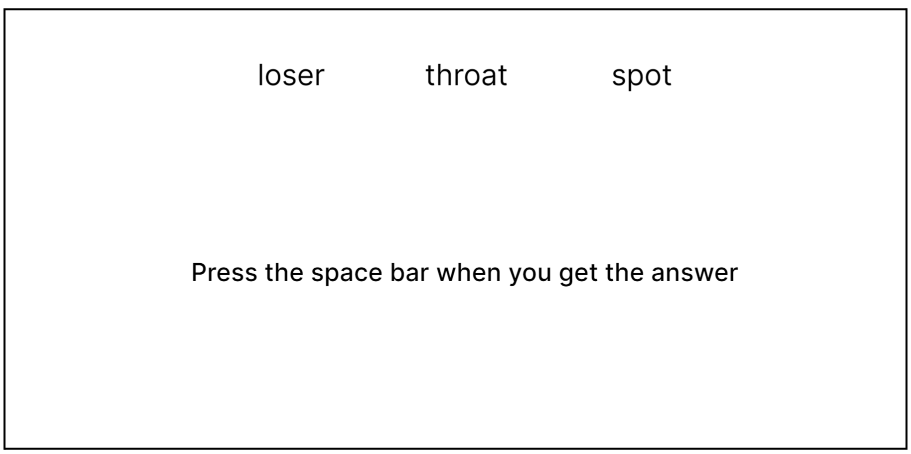


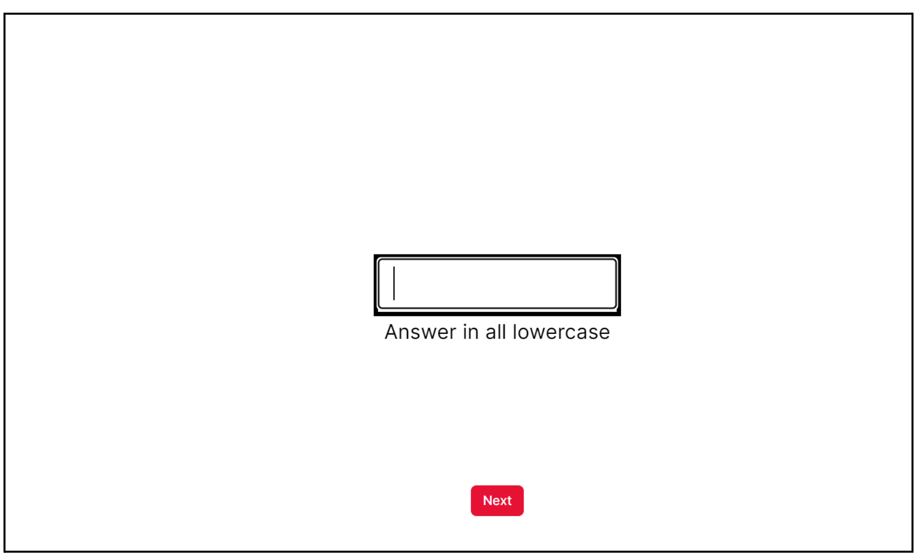
RAT Images


Task Instructions
You will be given 3 words and need to find the word that relates to all of them. Press SPACEBAR when you know the answer and then type it in (in lowercase). Answer as fast as you can. You have maximum 20 seconds per question.
Next


Task Instructions
Next will be 3 practice trials. The solution will be given after you complete a problem.
Next


Task Instructions
You have completed the practice trials! When you click next, there will be 15 real trials for you to complete. Please try your best and go as fast as possible.
Next


loser
throat
spot
Press the space bar when you get the answer


Answer in all lowercase
Next

List of Primed LDT Words

Type	Prime	Target	Condition (1=related 2= unrelated 3=nonword)
Practice	CHEAT	fail	1
Practice	TRUSTWOR THY	stare	2
Practice	MOTHER	buzzle	3
Trial	PICTURE	frame	1
Trial	DINER	supper	1
Trial	FOOTBALL	mud	1
Trial	BREEZEWA Y	walkway	1
Trial	MORAL	values	1
Trial	REEF	coral	1
Trial	COMPONEN TS	parts	1
Trial	SNEAK	preview	1
Trial	PRICELESS	valuable	1
Trial	MEAT	steak	1
Trial	NURSE	patient	1
Trial	CONSTRUC TION	build	1
Trial	REVENGE	kill	1
Trial	SIX	seven	1
Trial	THIN	small	1
Trial	DIAMETER	circle	1
Trial	COMPACT	disc	1
Trial	FREEZE	joke	1
Trial	VENT	anger	1
Trial	ATTEMPT	murder	1
Trial	EARNESTNE	honesty	1

	SS		
Trial	OBSTACLE	course	1
Trial	SEAM	thread	1
Trial	ESSENCE	meaning	1
Trial	CAUSE	why	1
Trial	OKAY	alright	1
Trial	BUILDING	tall	1
Trial	SCHEME	idea	1
Trial	ACHIEVEMENT	success	1
Trial	FINGER	hand	1
Trial	COOK	raw	1
Trial	RIGID	belief	1
Trial	WORSHIP	mean	2
Trial	DISEASE	amuse	2
Trial	MAYBE	ignore	2
Trial	BARTENDER	tongue	2
Trial	HAZE	wheat	2
Trial	INDIRECT	doctor	2
Trial	LEND	date	2
Trial	SALIVA	hoop	2
Trial	MURDERER	irregular	2
Trial	EXAM	tennis	2
Trial	SWEAR	pencil	2
Trial	FIND	hungry	2
Trial	FRISK	act	2
Trial	NEPHEW	broken	2
Trial	EXCISE	pan	2
Trial	COMPLEX	mouth	2
Trial	STOPPER	hate	2

Trial	EGGS	descend	2
Trial	SONNET	candle	2
Trial	CHAPTER	trash	2
Trial	RUDE	key	2
Trial	HER	computer	2
Trial	STAIRS	wind	2
Trial	PANCAKES	tree	2
Trial	WAGE	stain	2
Trial	CLOWN	unknown	2
Trial	TIGER	beach	2
Trial	OWE	many	2
Trial	WASTED	actor	2
Trial	HULA	hostess	2
Trial	MAD	thing	2
Trial	DIRECTION S	bee	2
Trial	HUNDRED	vemetables	3
Trial	BUG	perb	3
Trial	HUT	knighm	3
Trial	ICE	hib	3
Trial	INTROVERT	fizza	3
Trial	WRITE	mepicine	3
Trial	MIDDLE	cip	3
Trial	MYTH	poter	3
Trial	CLEAR	tuddle	3
Trial	CAMEL	zarry	3
Trial	CHIME	tost	3
Trial	COB	insrument	3
Trial	PICKLE	ebaphamt	3
Trial	ENRAGE	bemieve	3

Trial	RUM	miptane	3
Trial	DEGRADE	indale	3
Trial	INJECTION	eyo	3
Trial	CREATURE	guilpy	3
Trial	OWN	teght	3
Trial	FAMINE	sprine	3
Trial	VAULT	belp	3
Trial	BROIL	danper	3
Trial	SOUP	cleb	3
Trial	IMAGINE	colnege	3
Trial	AX	slame	3
Trial	BULLETIN	shob	3
Trial	GOOD	saln	3
Trial	TONIC	yarp	3
Trial	CHEMIST	silpy	3
Trial	REMAIN	fode	3
Trial	DUMB	zaugh	3
Trial	WICKER	strile	3

List of RAT Problems

Type	**Word1**	**Word2**	**Word3**	**Answer**
Practice	cottage	swiss	cake	cheese
Practice	cream	skate	water	ice
Practice	loser	throat	spot	sore
Question	show	life	row	boat
Question	night	wrist	stop	watch
Question	duck	fold	dollar	bill
Question	rocking	wheel	high	chair
Question	dew	comb	bee	honey

Question	fountain	baking	pop	soda
Question	preserve	ranger	tropical	forest
Question	aid	rubber	wagon	band
Question	flake	mobile	cone	snow
Question	cracker	fly	fighter	fire
Question	safety	cushion	point	pin
Question	cane	daddy	plum	sugar
Question	dream	break	light	day
Question	fish	mine	rush	gold
Question	political	surprise	line	party